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First insights on plasma orthodontics - Application of cold atmospheric pressure plasma to enhance the bond strength of orthodontic brackets

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ABSTRACT

Objective: The development of an ideal adhesive system has long been subject of research. Recent studies show that treatment with cold atmospheric pressure plasma (CAP) positively affects the bonding properties of enamel. Conditioning with CAP could therefore improve the mechanical and physical properties of bracket adhesives, e.g. Glass ionomer cement (GIC).
Material and methods: Laser-structured brackets (Dentaurum, Ispringen) were bonded onto 60 bovine mandibular incisors using different orthodontic adhesives. For 20 specimens FujiOrthoLC (GC America Corp, Alsip, USA) was used according to manufacturer's instructions. Another 20 specimens received a 60 s CAP-treatment (kINPen med, Neoplas tool, Greifswald, Germany) before bracket bonding, of which 10 were re-moistened before applying FujiOrthoLC and 10 remained dry. Onto 20 specimens, brackets were bonded with the Composite Transbond XT (3M/Unitek, St. Paul, USA) following manufacturer's instructions. The shear bond strength of brackets on the teeth was determined with the universal testing machine Zwick BZ050/TH3A (Zwick, Ulm, Germany).
Results: Brackets bonded with FujiOrthoLC in standard method, showed average shear bond strength of 5.58 ± 0.46 MPa. Specimens treated with plasma showed clinically unacceptable adhesion values (re-moistened group: 2.79 ± 0.38 MPa, dry group: 1.01 ± 0.2 MPa). Bonding onto dried out teeth also led to spontaneous bracket losses (4 of 10 specimens). The composite group (Transbond XT) showed clinically acceptable adhesion values (7.9 ± 1.03 MPa).
Conclusions: Despite promising potential, surface conditioning with CAP could not improve the adhesive properties of GIC. By contrast, a decrease in shear bond strength was noticed after CAP treatment. Further investigations have to show whether it is possible to increase the retention values of other orthodontic adhesives by CAP application and thus take advantage of positive characteristics and reduce side effects.

1. Introduction

Fixed "multibracket orthodontic appliances" function according to the principle of a metal wire that is attached to the teeth via anchoring elements ("brackets"). This wire serves as an ideal arch form on which the teeth align.

Since they were first described by George Newman as a new orthodontic bonding material in 1965 [1], epoxy adhesives have been routinely employed. However, this material also has some disadvantages: In order to create a micro-retentive surface for the composite the enamel must be conditioned with phosphoric acid, which leads to hard substance loss [2–4]. In some cases, the removal of brackets bonded with composites causes iatrogenic damage to the tooth, such as cracks in the enamel.

Moreover, conventional composites contain bisphenol-A (BPA). There has been some controversy about the biocompatibility of this degradation product of bis-GMA [4–9]. BPA has been described as an "endocrine disruptor" and has a weak estrogenic effect which can be detected in saliva and urine. It therefore poses a potential health risk [10] and its use should be avoided [11].

In view of all these downsides of conventional composites, the development of an ideal adhesive system is still a focus of research.

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Glass ionomer cements (GIC) show some interesting advantages in that they establish a chemical bond with tooth enamel which therefore does not require etching [2–4,12,13]. Brackets bonded with GIC cause fewer cracks in the enamel on removal at the end of the active treatment period [3,4,14,15]. GIC are biocompatible [16–19] and biomimetic [20–24]: they serve as fluoride-ion reservoirs and protect the tooth against cariogenic acids. Thus, GIC can be considered to be “ultimate protection” against caries [11,12,15,25–33].

GIC also shows low sensitivity to moisture [34]. This can be especially beneficial when working on lower and posterior teeth as they quickly become contaminated with saliva or blood [35–38].

Nevertheless, GIC has failed to become establish as a standard adhesion method for orthodontic brackets. Various studies have demonstrated that GIC show a weaker bonding strength than composites [3,13,19,29,39–43]. Brackets bonded with GIC show loss rates of around 25%, while the loss rate when using composites is around 7% [15].

If these problems were solved GIC would be a good option for bracket adhesives [4]. Orthodontic patients with poor oral hygiene would benefit especially from the use of GIC [30].

Surface conditioning with Cold Atmospheric Pressure Plasma (CAP) could be a useful means of improving the mechanical and physical properties of GIC. As already mentioned, GIC shows low sensitivity to moisture. The bond strength can even be enhanced when the enamel is moistened with water or saliva prior to the application of the brackets. One possible explanation for this phenomenon is the presence of 2-hydroxyethyl methacrylate (HEMA) - a water-soluble hydrophilic monomer- in GIC [2].

CAP has a positive influence on the bonding properties of tooth enamel [44]. By introducing free radicals CAP increases the surface energy of dentin and enamel and thus their hydrophilicity and penetrability [44–47]. The mechanisms underlying this conditioning are currently being discussed. Some studies suggest that the CAP-induced replacement of hydrocarbon groups with hydroxyl groups is responsible for the increased hydrophilicity [47–49]. CAP therefore has potential as a method of improving the properties of dental adhesive materials [44,48].

This study aims to improve the bond strength of GIC by increasing the hydrophilicity of dental enamel through conditioning with CAP.

2. Materials and methods

The experimental design was adapted from a study protocol established by Musabegovic [50] and carried out in accordance with the requirements of DIN 13990-1 and DIN 13990-2 [51,52].

Sixty disinfected bovine mandibular incisors were obtained (Rocholl GmbH, Aglasterhausen, Germany) and embedded in cylindrical blocks of fast curing, two-component embedding resin (Technovit 4071, Heraeus Kulzer GmbH, Wehrheim, Germany), exposing the facial surface of the teeth. All specimens were then kept wet and stored in ultrapure water. An area measuring 5 × 5 mm, framing the location of the lowest labial curvature was marked on the teeth. This area was cleaned with an oil-free, non-fluoridated paste (15 s, 6000 rpm) and thoroughly rinsed with water (15 s). Laser-structured brackets (Discovery®-Brackets for tooth number 8, Dentaurum GmbH & Co. KG, Ispringen, Germany) were bonded onto the specimens using various different orthodontic bonding materials as adhesives.

The specimens were divided into four groups: In Group 1 ($n=20$) brackets were bonded with a light-curing resin-reinforced GIC (Fuji Ortho LC, GC America Corp, Alsip, USA) according to the manufacturer's instructions. Specimens in Group 2 ($n=10$) and Group 3 ($n=10$) were subjected to treatment with Argon-CAP (kINPen med, neoplas tool GmbH, Greifswald, Germany) for 60 s before application of Fuji Ortho LC. The specimens of Group 2 were re-moistened before bracket-bonding using a drop of ultrapure water that was carefully absorbed by sterile gauze. Prior to bracket-bonding the specimens of Group 3 remained dried out by means of the plasma jet. Group 4 ($n=20$) served as control group in which brackets were bonded using a standard composite (Transbond XT, 3M/Unitek, St. Paul, USA). Following the bonding procedure, all specimens were stored in ultrapure water at room temperature for 24 h.

The maximum force (FMax) at which the brackets broke off from the tooth surface was measured by a universal testing machine (Zwick BZ050/TH3A, Zwick GmbH&Co. KG, Ulm, Germany) as described by Musabegovic [50]. These values were then converted into shear bond strength (R_s) by taking into account the base area of the brackets (12.12 mm²) and using the following formula:

$$R_S = \frac{FMax}{A}$$

3. Results

Brackets bonded with Fuji Ortho LC in a standard procedure (Group 1), showed an average shear bond strength of 5.58 ± 0.46 MPa. Specimens that had been treated with plasma showed clinically unacceptable adhesion values: 2.79 ± 0.38 MPa in the re-moistened group (Group 2) and 1.01 ± 0.2 MPa in the dry group (Group 3). The procedure used in Group 3 also led to spontaneous bracket loss (4 out of 10 specimens). Group 4 (Transbond XT) showed clinically acceptable adhesion values (7.9 ± 1.03 MPa) (Table 1).

4. Discussion

Despite promising potential, the adhesive properties of glass ionomer cement were not improved by surface conditioning with CAP. Reynolds considers bond strength of 5.9–7.8 MPa to be necessary for successful clinical bonding [53]. On this basis, only the results of Group 4 are acceptable for routine clinical use. The results for Group 1 were just outside the recommended range.

Contrary to expectations, teeth treated with CAP showed weaker shear adhesion strength than teeth without CAP surface conditioning. Other studies have demonstrated that CAP effects

Table 1
The maximum force (FMax) was measured by a universal testing machine and then converted into shear bond strength values (R_s) by taking into account the base area of the brackets. The brackets used in this study are characterized by a laser structured adhesive base of 12.12 mm².

	FMax [N]	**R_s [MPa]** $A=12.12$ mm²
Group 1 ($n=20$) Fuji ORTHO LC (GC America Corp, Alsip, USA)	67.62 ± 5.56	**5.58 ± 0.46**
Group 2 ($n=10$) CAP, re-moistened enamel, Fuji ORTHO LC	33.76 ± 4.57	**2.79 ± 0.38**
Group 3 ($n=6$) CAP, dry enamel, Fuji ORTHO LC	12.25 ± 2.46	**1.01 ± 0.2**
Group 4 ($n=20$) Transbond XT(3 M/Unitek, St Paul, USA)	95.84 ± 12.45	**7.9 ± 1.03**

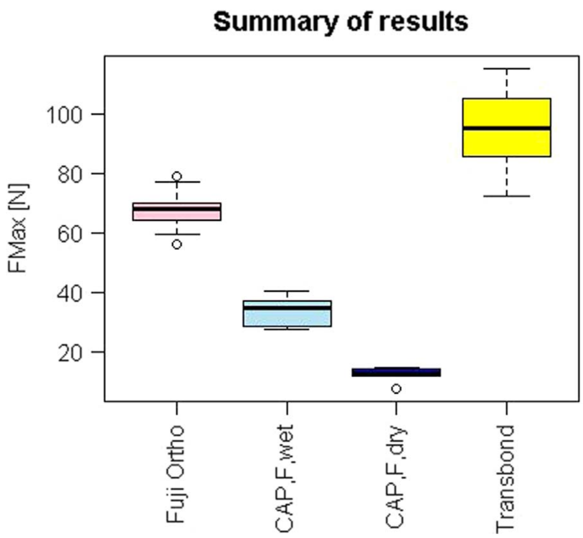

Fig. 1. Boxplots showing the range of the maximum forces (FMax) at which the brackets broke off from the tooth surface. Brackets bonded with Fuji Ortho LC on dry enamel that was conditioned with cold atmospheric pressure plasma (CAP, F, dry) broke off when forces of 12.25 ± 2.46N were applied with a universal testing machine. The specimens treated with CAP and bonded with Fuji Ortho LC on wet enamel (CAP, F, wet) withstood a higher range of force (33.76 ± 4.57N). Brackets bonded on teeth surfaces that were not conditioned with CAP resisted higher forces (Fuji Ortho LC: 67.62 ± 5.56N, Transbond XT: 95.84 ± 12.45).

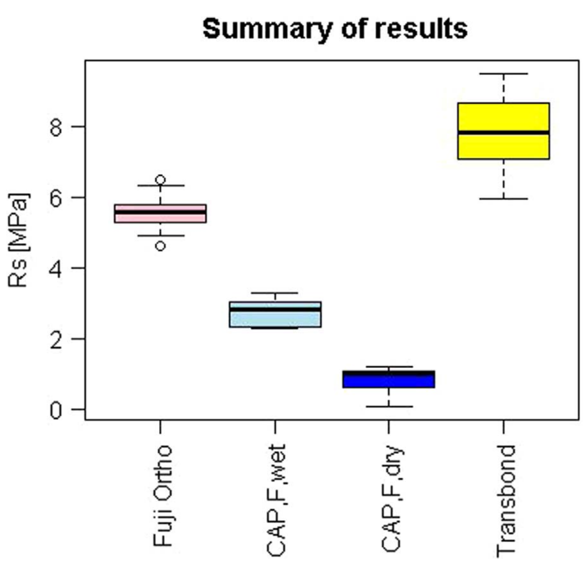

Fig. 2. Boxplots showing the range of shear bond strengths (R_s) of the different specimens. Brackets bonded with Fuji Ortho LC on wet or dry teeth surfaces that had been conditioned with cold atmospheric pressure plasma (CAP, F, wet and CAP, F, dry) showed weaker shear bond strengths than teeth without CAP surface conditioning (Fuji Ortho, Transbond).

desirable surface modifications for bonding to enamel [44]. 60–120-s surface treatment of dentin slices with argon-CAP with the addition of 1% O_2 resulted in the strongest improvement in surface wettability [49]. In this study, however, no oxygen was added to the argon-CAP for two practical reasons: first, the admixture of O2 reduces the height of the tip of the plasma jet and thus makes it difficult to handle. Second, the kINPen med is only certified for intraoral use when operated with pure argon-CAP.

Compared to other studies on the shear adhesion strength of GIC and composites, all results of this study appear low. Bishara tested Fuji Ortho LC and Transbond XT on freshly extracted human teeth. His findings are both in the range of clinically acceptable bond strength (Fuji: 6.5 ± 1.9 MPa, Transbond: 10.4 ± 2.8) [54]. He did, however, use a polyacrylic acid enamel conditioner before applying GIC. The use of conditioners for GIC is controversial. Gaworski suggests that the bond strength of GIC may be increased by etching or by conditioning the enamel before bonding [15]. Cacciafesta states that it does not appear to be necessary to condition enamel surfaces when using Fuji Ortho LC [2]. Current studies show that CAP improves the penetrability of intact enamel by removing the water in pores and creating a hydrophilic surface [48]. This allows the adhesive to form longer resin tags. This leads to improved micro-mechanical interlocking. Acid-conditioners are manufactured for the same reason: to mildly etch and condition the enamel. This study did not use a conditioner for GIC, since it is not part of the standard manufacturers' instructions for Fuji Ortho LC, but only described as "optional". Future studies should investigate whether a conditioner for GIC enhances the bond strength of brackets and whether it can be replaced by CAP surface conditioning.

Another point to be considered is the way in which Fuji Ortho LC was dispensed. Klockowski sees high technique sensitivity as one major disadvantage of GIC [14]. In this study, a powder/liquid-system was used for economical reasons, permitting greater flexibility in the delivery of the total needed quantity. However, a capsule system would guarantee a correct and more homogenous ratio of the components and may therefore be more suitable for future experiments (Figs. 1 and 2).

5. Conclusions

This study is a first trial of CAP surface conditioning as a method of enhancing the bond strength of orthodontic adhesives. First insights on how to improve the experimental design were obtained. Future investigations should demonstrate how the mechanical properties of orthodontic adhesives can be successfully improved hydrophilizing or hydrophobizing the tooth enamel by CAP. The aim remains to utilize CAP in orthodontics to make use of the positive characteristics of certain adhesives and to mitigate negative side effects of others.

Conflict of interest statement

The authors state that they do not have any financial or personal relationships with other people or organizations that could inappropriately influence their work.

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